

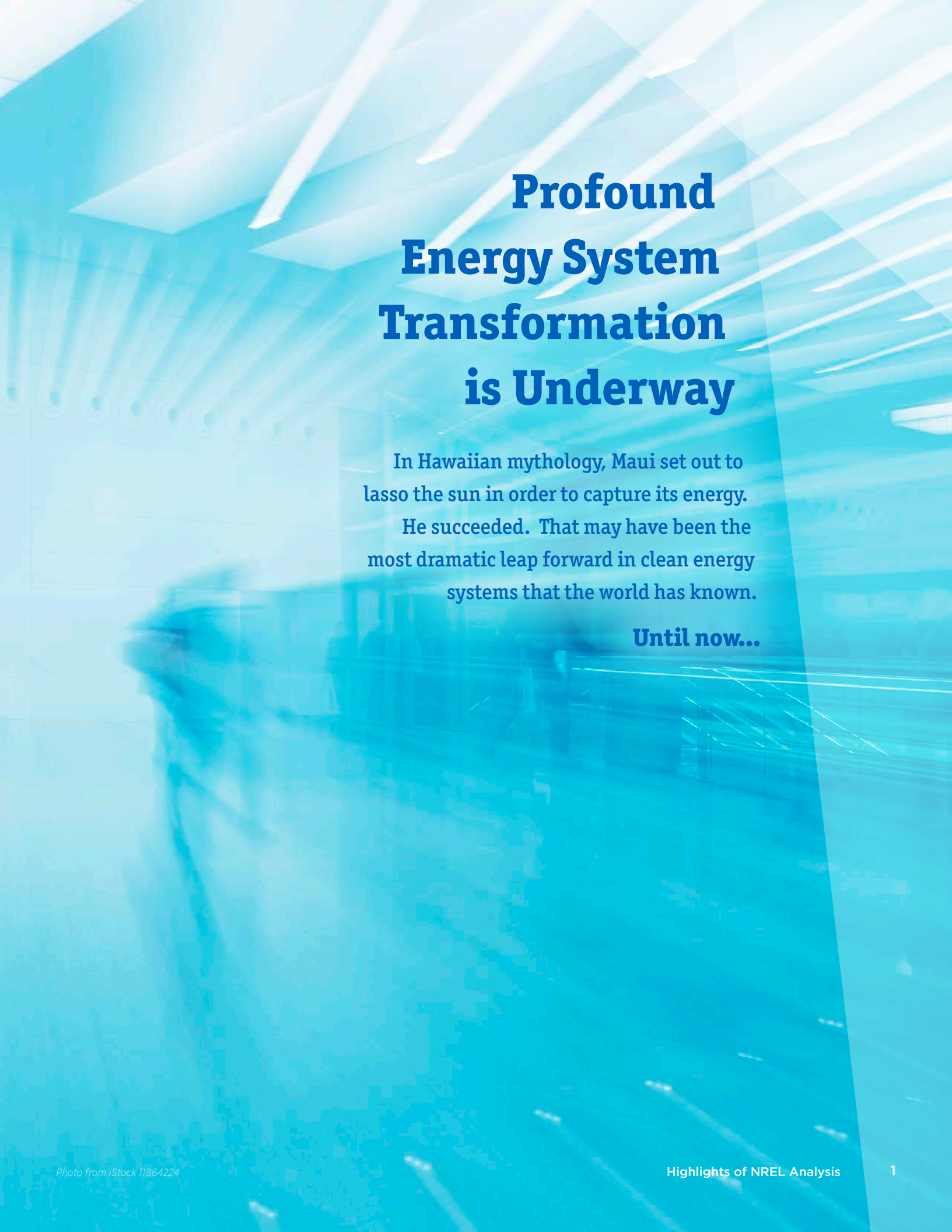
# Realizing a Clean Energy Future

Highlights of NREL Analysis

## Table of Contents

Profound Energy System Transformation is Underway .....	1
Our Contributions. ....	4
A Clean Energy Future Has Arrived .....	5
Renewable Industry Continues to Grow .....	6
Renewable Energy Technical Potential is Enormous .....	7
Comprehensive Studies Validate Opportunity for U.S. Renewables to Provide Clean Electricity and Transportation .....	8
Realizing Clean Energy's Potential: Challenge and Opportunity .....	9
Renewables and Natural Gas: Competition or Collaboration? .....	10
NREL Calculates Emissions and Costs of Power Plant Cycling Necessary for Increased Wind and Solar in the West. ....	11
NREL, MIT Study: PV Manufacturing Costs Not Driven Primarily by Labor .....	11
NREL Tools Aid Deployment of Resilient Clean Energy Solutions Around the World .....	12
NREL Financial Analysis Reduces Investment Risk and Helps Mobilize Capital for Renewable Energy Projects .....	12
Systems-Level Thinking Essential as Connections Grow Between Energy, Environment, and Economy .....	13
Energy Systems Integration: A Convergence of Ideas .....	14
Disaster Resiliency and Recovery: Systems Thinking Helps Communities Build and Rebuild Green. ....	14
NREL Support for Clean Transportation Leads to Clean Parks, Clean Cities .....	15
Energy Informatics – Turning Energy Data Into Actionable Information .....	15
Fundamental Analysis: Documenting Land and Water Requirements of Energy Systems .....	16
Emerging Economies are Reshaping the Energy and Geopolitical Landscape .....	17
21st Century Power Partnership Enabling Power System Transformation .....	18
Expert Assistance Supports Low-Emission Development Around the World .....	19
Reports for International Energy Agency Explore Best Practices for Using Energy Models and Next-Generation Policies to Support RE .....	19
OpenEI Positions Energy Department as Leader in Global Energy Dialogue .....	20
JISEA: Looking Beyond Clean Energy .....	21
NREL Analysis: 2013 Highlights .....	22
Report Card: Making an Impact. ....	24





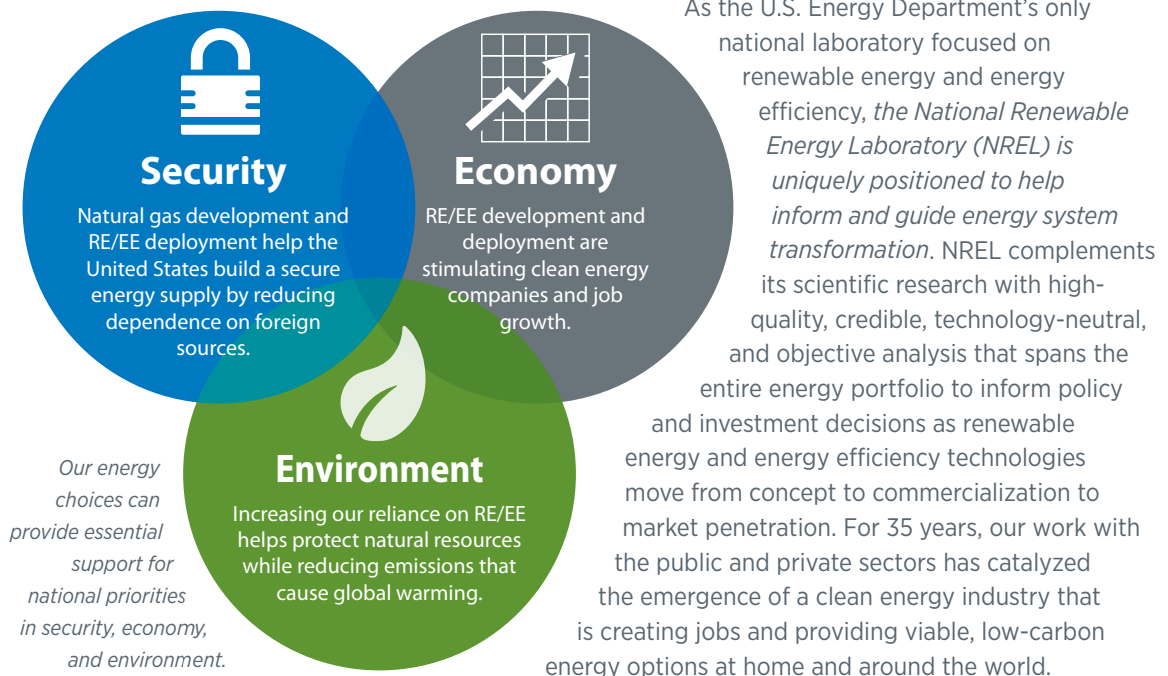
# **Profound Energy System Transformation is Underway**

In Hawaiian mythology, Maui set out to lasso the sun in order to capture its energy. He succeeded. That may have been the most dramatic leap forward in clean energy systems that the world has known.

**Until now...**

**T**oday, another profound transformation is underway. A combination of forces is taking us from a carbon-centric, inefficient energy system to one that emphasizes efficiency and draws from diverse energy sources—including the sun. In 2012, more than half of total net additions to global electric generating capacity came from renewable sources. Since 2008, U.S. electricity generation from wind and solar power has more than doubled. Sharp and largely unforeseen growth in the U.S. shale gas market has altered the dynamics of the global energy landscape and helped spark a renaissance in U.S. manufacturing. These changes, together with improvements in energy efficiency and a changing transportation sector, have contributed to a drop in U.S. carbon emissions, which hit a 20-year low in 2012.

At the same time, the business of energy is changing from one focused on kilowatt hours to one focused on services. The roles that distribution and transmission play could change dramatically as we move toward an energy system that is more diverse, more dispersed, and more carbon neutral. Energy is becoming a more essential component of strategies to safeguard and improve our security, economy, and environment.



In 2013, NREL realigned the organization and elevated the position of analysis within the laboratory in order to strengthen and find synergies among our analytical capabilities. Our new Energy Analysis and Decision Support organization provides services that:

- Inform decisions in a technology-neutral manner
- Guide investment decisions and inform policy

- Remove or reduce barriers in markets, information, or policy
- Examines geographic scales ranging from site to regional, country, or multi-country and time scales ranging from near term to distant future.

We believe that these changes will help NREL continue to provide trusted insight and thought leadership that informs and shapes the global energy dialogue and global energy systems in ways that support the strategic interests of the United States and the international community.

Mythic heroics have given way to real-world priorities in security, economy, and environment as drivers of energy system transformation. More than 50% of global power investments are in clean energy systems, and the renewables industry continues to grow around the world. In the pages that follow, we showcase ways in which NREL's thoughtful, sound analyses have helped us reach a clean energy future.



**Bobi Garrett**

Deputy Lab Director –  
Strategic Programs and  
Partnerships

*NREL/Alliance for  
Sustainable Energy*

*Photo by Dennis Schroeder,  
NREL 20282*



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*NREL/Alliance for  
Sustainable Energy*

*Photo by Dennis Schroeder,  
NREL 28182*



**Doug Arent**

Executive Director –  
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Acting Director –  
*NREL Strategic Energy  
Analysis Center*

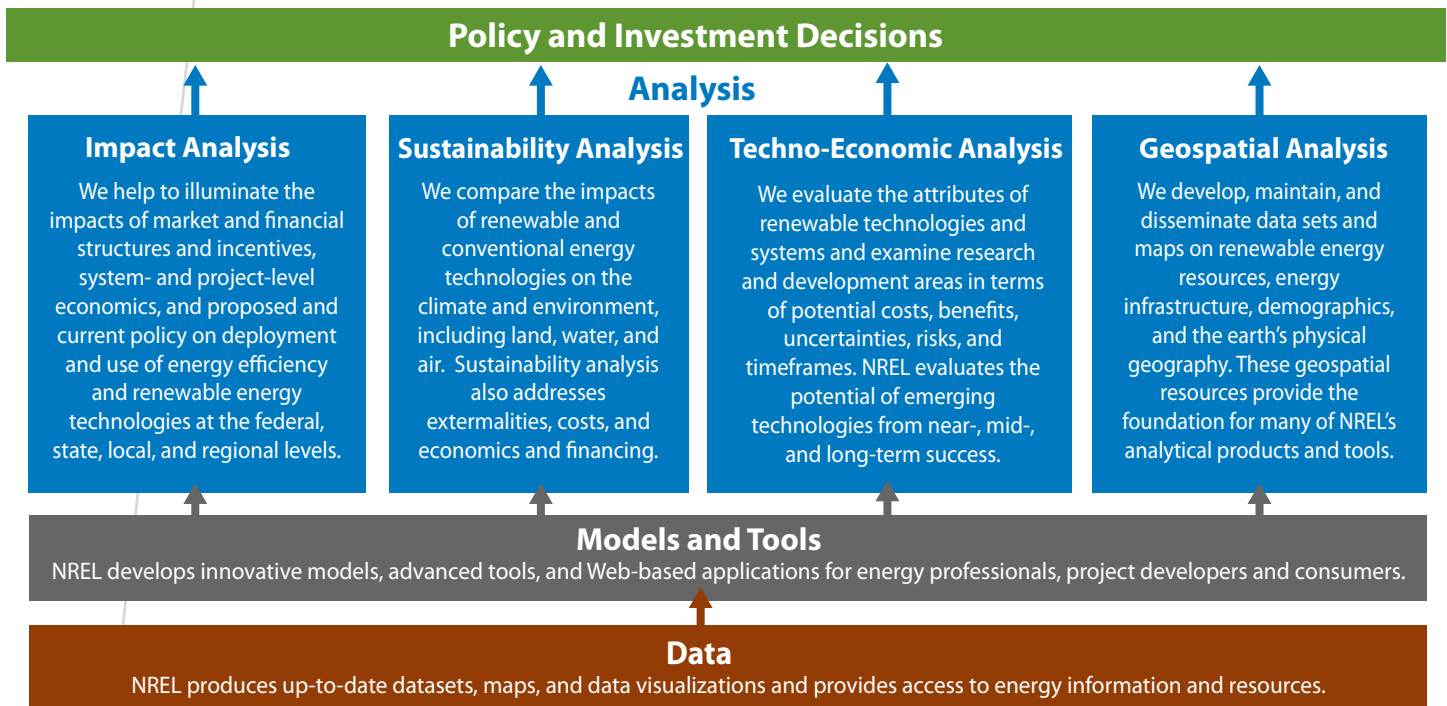
*Photo by Dennis Schroeder,  
NREL 20130*

## Our Contributions

NREL analysis helps government policymakers, project developers and investors, utilities, and others, both at home and abroad, address the challenges of and understand the trade-offs posed by expanding renewables within today's energy system. Our work sets the standard for transparency and increases analytical opportunities for others by including publication of foundational datasets whenever possible.

NREL's analysis:

- Illuminates system operation with high penetration renewables
- Informs federal, state, and regional policymaking and planning
- Estimates the impacts of RE/EE technologies, including costs, co-benefits, and value
- Informs future climate negotiations.



### Areas of Analysis Expertise

- Power systems and thermal systems
- Built environment and communities
- Transportation and mobility
- Manufacturing and economic impact
- Land, water, and energy connections

*Building on a foundation of robust data and innovative models and tools, many of which we developed, NREL prepares credible, objective analyses that inform policy and investment decisions as renewable energy and energy efficiency technologies move from innovation through integration.*



*...Your team is superb. It is always energizing to come to the lab and hear about the many types of analysis projects the team is working on. And it was particularly inspiring to see so many young analysts who are strong technically, extremely articulate, and passionate about their work.*



— Susan Tierney, Managing Principal  
The Analysis Group



A person's hands are shown holding a dandelion seed head. The background is a bright, golden sunset or sunrise, with a large, out-of-focus sun on the left side. The overall tone is warm and optimistic.

# A Clean Energy Future Has Arrived

Thanks to technological advances,  
policy support, and improved  
understanding of deployment  
potential informed by robust analysis,  
we are increasingly powering our  
electricity and transportation systems  
with clean, renewable energy sources.

A clean energy future is  
here and expanding.

### Renewable Industry Continues to Grow Rapidly

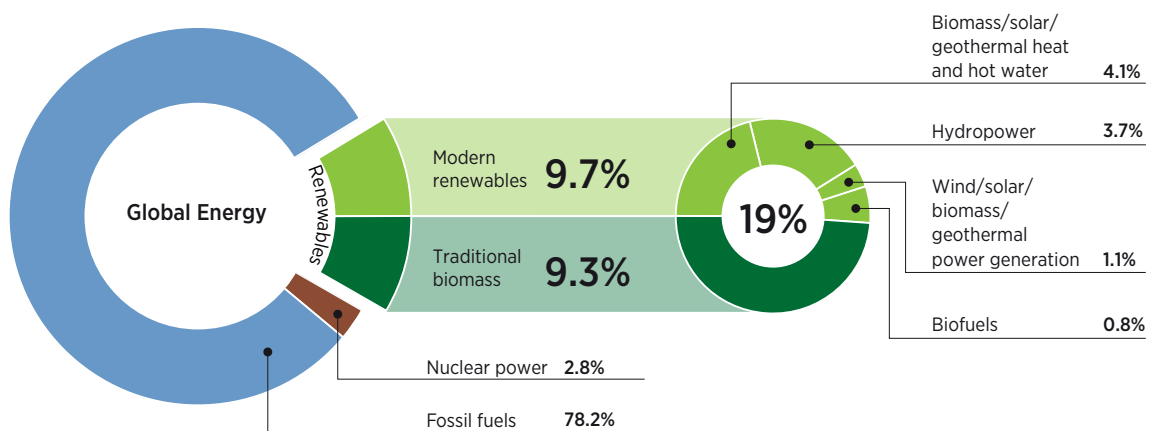
Between 2000 and 2011, installed global renewable electricity grew by 72% (from 748 GW to 1,285 GW), accounting for 22% of all global electricity generation in 2011. According to recent global energy projections, this momentum will continue. The majority of electric generating capacity additions through 2035 will come from natural gas and renewable energy sources rather than traditional fossil fuels. Overall, renewable capacity is expected to triple by 2035, supplying close to one-third of electricity globally.

The two key factors fueling this growth are (1) increasing cost-competitiveness of wind and solar technologies and (2) accelerating deployment of renewables in emerging markets.

In ***The Past and Future Cost of Wind Energy***, a 2012 report prepared jointly by NREL and Lawrence Berkeley National Laboratory for the International Energy Agency, analysts found that the majority of studies indicate continued cost reductions on the order of 20%–30% through 2030. Moreover, falling turbine prices are expected to drive a historically low levelized cost of energy for current installations.

Meanwhile, the installed price of solar photovoltaic power systems in the United States fell substantially in 2012 and through the first half of 2013, according to analysis of project-level data for more than 200,000 individual residential, commercial, and utility-scale PV systems, representing 72% of the grid-connected PV capacity installed nationwide through 2012. The decline is largely attributable to falling module prices. The analysis was conducted for the Energy Department's SunShot Initiative.

In ***International Trade of Biofuels***, NREL tracks a steady growth in global biofuels production, from 4 billion gallons to 26 billion gallons between 2000 and 2011. Today, biofuels provide around 3% of total road transport fuel globally (on an energy basis).



*Increasing cost-competitiveness of wind and solar technologies and accelerating deployment of renewables in emerging markets are helping renewables capture a growing share of global energy supply.*



Primary energy demand for bioenergy – biofuels for transport, biobased products, and biogas to produce electricity and heat—is expected to more than double by 2035.

Learn More: [www.nrel.gov/docs/fy12osti/53510.pdf](http://www.nrel.gov/docs/fy12osti/53510.pdf)  
[www.nrel.gov/docs/fy13osti/56792.pdf](http://www.nrel.gov/docs/fy13osti/56792.pdf)

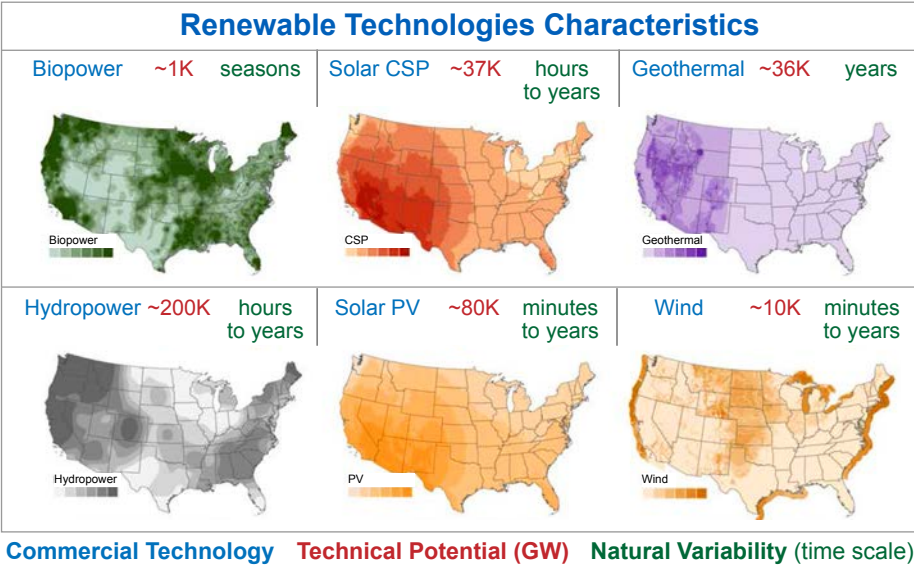
Renewable Energy Technical Potential is Enormous

Numerous studies have quantified the technical potential of renewable energy—the achievable energy generation of a particular technology given system performance, topographic limitations, and environmental and land-use constraints. In its 2012 report **U.S. Renewable Energy Technical Potentials: A GIS-based Analysis**, NREL standardized the findings of many studies to create a comprehensive look at renewables’ technical potential.

Drawing on spatial analysis, available land area, installed capacity, and electric generation, NREL presented state-by-state findings for six different renewable electricity generation technologies: utility-scale photovoltaics (both urban and rural), concentrating solar power, land-based wind power, offshore wind power, biopower, and enhanced geothermal systems.

While potential for renewables tends to be geographically concentrated (solar in the Southwest, wind in the central plains), NREL found potential for at least one renewable technology in nearly every state. In total, renewables show the potential to generate 481,800 terawatt-hours, more than 100 times the total U.S. electricity consumption in 2011.

Learn More: [www.nrel.gov/gis/re\\_potential.html](http://www.nrel.gov/gis/re_potential.html)



In U.S. Renewable Energy Technical Potentials: A GIS-based Analysis (NREL 2012), NREL found enormous technical potential for renewables in the United States. Technical potential helps establish an upper-boundary estimate of development potential. Other measurements—resource, economic, and market—help determine the total potential of a technology in a geographic region.

## Comprehensive Studies Validate Opportunity for U.S. Renewables to Provide Clean Electricity and Transportation

NREL has led or contributed to several key studies that have helped illuminate what is possible for renewable technologies.

A 2013 NREL study—***Beyond Renewable Portfolio Standards: An Assessment of Regional Supply and Demand Conditions Affecting the Future of Renewable Energy in the West*** by David J. Hurlbut, Joyce McLaren, and Rachel Gelman—indicates that by 2025 wind and solar power electricity generation could become cost-competitive without federal subsidies if new renewable energy development occurs in the most productive locations.

Building on earlier analysis the lab conducted for the Western Governors’ Association, the report compares the cost of renewable electricity generation (without federal subsidy) from the West’s most productive renewable energy resource areas—including any needed transmission and integration costs—with the cost of energy from a new natural gas-fired generator built near the customers it serves.

“The electric generation portfolio of the future could be both cost effective and diverse,” said NREL Senior Analyst David Hurlbut. “If renewables and natural gas cost about the same per kilowatt-hour delivered, then value to customers becomes a matter of finding the right mix.”

**Learn More:** [www.nrel.gov/docs/fy13osti/57830-2.pdf](http://www.nrel.gov/docs/fy13osti/57830-2.pdf)

## Envisioning 2050: Potential Energy Futures

### Today’s Renewable Technologies Supply 80% of U.S. Electricity

Can renewable energy technologies play a dominant role in U.S. power generation?

The ***Renewable Electricity Futures Study*** begins to answer this important question, analyzing a range of future scenarios to better understand potential renewable resource and power grid infrastructure and operating challenges and opportunities.

Using NREL’s Regional Energy Deployment System (ReEDS) model and the industry tool GridView, analysts found that renewable technologies that are commercially available today, in combination with a more flexible electric system, could supply 80% of total U.S. electricity generation in 2050 while meeting electricity demand on an hourly basis in every region of the country.

This result was consistent for multiple combinations of renewable technologies and a variety of supply- and demand-side approaches to increasing system flexibility.

To achieve high levels of renewable penetration in the future, more work is needed to continue lowering the cost of renewable energy technologies, while increasing their reliability, expanding transmission, and improving grid integration.

**Learn More:** [www.nrel.gov/re\\_futures/](http://www.nrel.gov/re_futures/)

### Collaborative NREL/ANL Study Explores Pathways to 80% Cuts in Petroleum Use

NREL collaborated with Argonne National Laboratory (ANL) on the ***Transportation Energy Futures Study***, an assessment of avenues to reach deep cuts in petroleum use and greenhouse gas (GHG) emissions in the transportation sector.

“Transportation is an engine of economic strength, and it presents significant opportunities to cut oil dependence while taking a bite out of GHG emissions,” NREL Senior Analyst Austin Brown said. “Transportation accounts for 71% of total U.S. petroleum consumption and 33% of our nation’s total carbon emissions.”

The study revealed strategies and combinations of strategies to potentially reduce petroleum use and GHG emissions in the transportation sector by more than 80% by 2050.

“Uncovering many options increases our confidence that a clean transportation solution is possible in the long term,” Brown said.

**Learn More:** [www.nrel.gov/analysis/transportation\\_futures/](http://www.nrel.gov/analysis/transportation_futures/)

### Solar Technologies Could Satisfy 27% of U.S. Electricity Demand

The ***SunShot Vision Study*** provides an in-depth assessment of the potential for solar technologies to meet a significant share of electricity demand in the United States during the next several decades. The DOE study explores a future in which the cost of solar technologies decreases by about 75% between 2010 and 2020, in line with the SunShot Initiative’s cost targets.

Using two models developed by NREL to evaluate a SunShot scenario and a reference scenario, the study projects that solar photovoltaic and concentrating solar power technologies could satisfy roughly 14% of U.S. electricity demand by 2030 and 27% by 2050.

At these levels of solar power, annual U.S. electricity-sector carbon dioxide (CO<sub>2</sub>) emissions are estimated to be significantly lower in the SunShot scenario than in the reference scenario: 8%, or 181 million metric tons (MMT), lower in 2030, and 28%, or 760 MMT, lower in 2050.

Across all market sectors, the lower electricity prices in the SunShot scenario translate into about \$30 billion in annual cost savings by 2030 and \$50 billion in annual savings by 2050 compared to the reference scenario.

**Learn More:** [www1.eere.energy.gov/solar/sunshot/](http://www1.eere.energy.gov/solar/sunshot/)





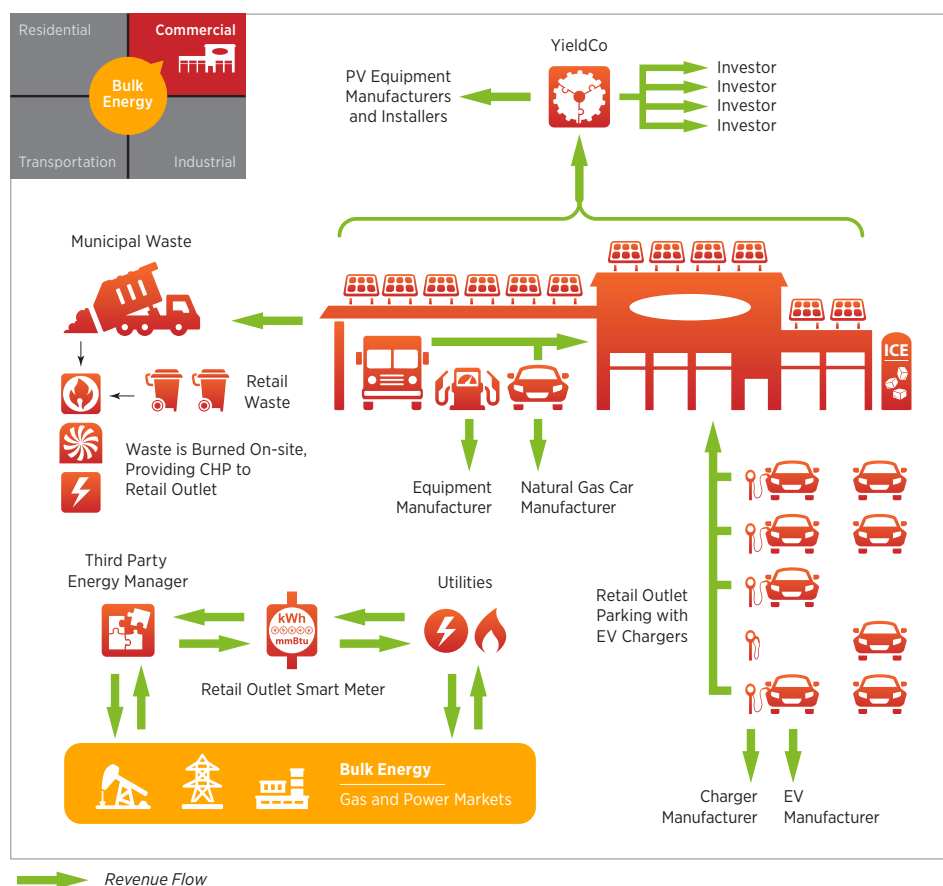
# Realizing Clean Energy's Potential: Challenge and Opportunity

NREL analyzes technologies, policies, and markets to help enable basic and applied clean energy innovation, accelerate technology introduction and adoption, reduce investment risk, and allow for integration of renewable technologies at scale. A growing body of work also examines synergies between renewable technologies and natural gas.



## Renewables and Natural Gas: Competition or Collaboration?

Natural gas and renewable energy each contribute to economic growth, energy independence, and carbon mitigation, sometimes independently and sometimes together. New technologies, policies, and practices are emerging that may allow businesses to consider these energy sources as more “bankable” partners. Natural gas and renewables can be key elements of system-level solutions that stand to transform the national energy landscape.



JISEA and NREL are exploring value propositions associated with energy solutions that include both natural gas and renewable energy. This line of study identifies revenue opportunities that emerge from systems-level perspectives in “bulk energy” (large-scale electricity and natural gas production, transmission, and trade) and four “distribution edge” subsectors: industrial, residential, commercial, and transportation. Commercial opportunities, shown here, include new revenue flows for natural gas and electric car manufacturers, investors, and infrastructure suppliers, as well as retail centers.

In a growing body of work, NREL and the Joint Institute for Strategic Energy Analysis (JISEA) look at the impacts and implications of the U.S. shale gas revolution on domestic and global energy markets.

Much of the current discourse considers renewables and natural gas in isolation or concentrates on the competitive impacts of one on the other. Instead, NREL explores

potential synergies between natural gas and renewable energy in the U.S. electric power and transportation sectors.

Synergies exist at many levels, from hybrid systems that optimize assets, such as smart buildings with both PV and natural gas combined heat and power systems, to transmission corridors that serve both technologies, to investment portfolios that address business and financial risks through asset diversification.

Capitalizing on both renewable energy and natural gas can unlock new revenue streams, including wholesale market opportunities for the distribution edge, upstream and downstream arbitrage opportunities from shared infrastructure, and energy services that offer the customer resiliency, reliability, and reduced costs.

**Learn More:** [www.JISEA.org/natural\\_gas.cfm](http://www.JISEA.org/natural_gas.cfm)

### ***NREL Calculates Emissions and Costs of Power Plant Cycling Necessary for Increased Wind and Solar in the West***

New research from NREL quantifies the potential impacts of increasing wind and solar power generation on the operators of fossil-fueled power plants in the West. To accommodate higher amounts of wind and solar power on the electric grid, utilities must ramp down and ramp up or stop and start conventional generators more frequently to provide reliable power for their customers—a practice called cycling.

Phase 2 of the ***Western Wind and Solar Integration Study*** (WWSIS-2) finds that the carbon emissions induced by more frequent cycling are negligible (<0.2%) compared with the carbon reductions achieved through the wind and solar power generation evaluated in the study. Sulfur dioxide emissions reductions from wind and solar are 5% less than expected because of cycling of fossil-fueled generators. Emissions of nitrogen oxides are reduced 2% more than expected. The study also finds that high levels of wind and solar power would reduce fossil fuel costs by approximately \$7 billion per year across the West, while incurring cycling costs of \$35 million to \$157 million per year. For the average fossil-fueled plant, this results in an increase in operations and maintenance costs of \$0.47–\$1.28 per megawatt-hour (MWh) of generation.

“From a system perspective, high proportions of wind and solar result in lower emissions and fuel costs for utility operators,” NREL’s Debra Lew said. “The potential cycling impacts offset a small percentage of these reductions.”

**Learn More:** [www.nrel.gov/wwsis](http://www.nrel.gov/wwsis)

### ***NREL, MIT Study: PV Manufacturing Costs Not Driven Primarily by Labor***

Production scale, not lower labor costs, drives China’s current advantage in manufacturing solar photovoltaic (PV) energy systems, according to a report by NREL and the Massachusetts Institute of Technology (MIT) published in the journal *Energy & Environmental Science* (impact score = 11.653).

Although the prevailing belief is that low labor costs and direct government subsidies for PV manufacturing in China account for that country’s dominance in

“ *There is considerable misunderstanding in the global PV industry today about the difference between production cost and sales price, leading to many bad investment decisions. By defining and focusing attention on the minimum sustainable price of PV-module manufacturing, the authors [of an NREL/MIT study] provide a sound basis for decision-making by both industry and government.* ”

— Paul Basore  
Hanwah  
Solar America

PV manufacturing, the NREL/MIT study (“Assessing the Drivers of Regional Trends in Solar Photovoltaic Manufacturing”) shows that a majority of the region’s current competitive advantage comes from production scale enabled, in part, through preferred access to capital (indirect government subsidies) and resulting supply chain benefits.

By developing manufacturing cost models, the team of researchers examined the underlying causes for shifts from a global network of manufacturers to a production base that is now largely based in China.

The study shows that China’s historical advantage in low-cost manufacturing is mainly due to advantages of production scale and offset by other country-specific factors, such as investment risk and inflation. The authors also found that technology innovation and global supply chain development could enable increased manufacturing scale around the world, resulting in broader, subsidy-free PV deployment and the potential for manufacturing price parity in most regions.

Excluding shipping costs, the team estimated that China-based manufacturers have a 23% advantage in minimum sustainable price advantage over U.S.-based manufacturers today. Scale and supply-chain advantages account for the majority of the advantage could be replicated by U.S.-based manufacturers.

**Learn More: DOI: 10.1039/C3EE40701B**

### ***NREL Financial Analysis Reduces Investment Risk and Helps Mobilize Capital for Renewable Energy Projects***


In roundtable discussions between renewable energy and financing experts convened by NREL in 2012, securitization (the bundling of illiquid financial assets into tradable investment products) emerged as a potentially useful mechanism for attracting investment from new sources of capital such as pension programs and sovereign wealth funds.

To turn the idea into action, NREL convened the Solar Access to Public Capital (SAPC) working group with the mission of enabling securitization of solar PV assets in the marketplace. The working group, which includes more than 130 members including leading developers, law firms, financiers, and analytic firms, released standard contracts designed to lower transaction costs and facilitate pooling of cash flows for capital market investment.

A 2013 NREL report—***Financing U.S. Renewable Energy Projects Through Public Capital Vehicles: Qualitative and Quantitative Benefits*** by Michael Mendelsohn and David Feldman—finds that increased access to public capital has the potential to reduce the cost of solar and wind energy and significantly increase the availability of project funds. Forbes mentioned the report, and Clean Energy Authority, Greentech Media, SNL, and others covered NREL’s body of work on securitization for renewable energy financing.

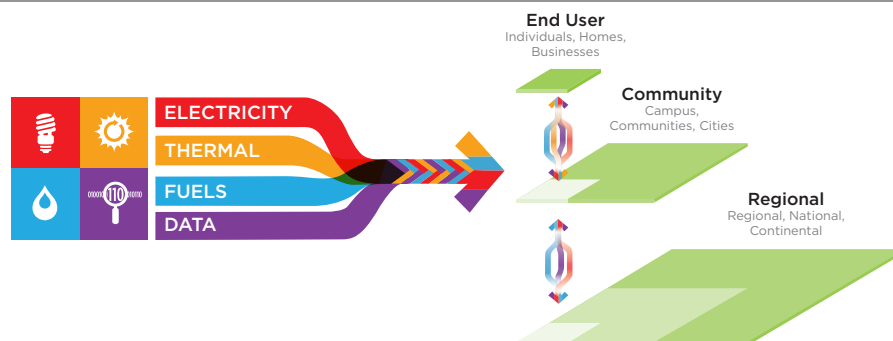
**Learn More: [www.nrel.gov/docs/fy13osti/58315.pdf](http://www.nrel.gov/docs/fy13osti/58315.pdf)  
[www.financere.nrel.gov/](http://www.financere.nrel.gov/)**





# **Systems-Level Thinking Essential as Connections Grow Between Energy, Environment, and Economy**

“Systems thinking” is a discipline for seeing wholes. It is a framework for understanding interrelationships rather than individual elements—for seeing patterns of change rather than static snapshots. NREL’s big picture thinking helps policymakers and energy planners understand the impacts of existing and proposed legislation, policy, and plans on renewable energy development and deployment at the local, state, regional, and national levels.



### Energy Systems Integration: A Convergence of Ideas

*The convergence of energy disciplines, environmental factors, and economic challenges is demanding a new focus on world energy goals and how we will meet them. NREL is building new facilities and capabilities to advance the science of energy systems integration.*

Our energy system includes not only renewable, nuclear, and fossil energy sources but also electrical, thermal, and fuel energy pathways that convert and deliver energy services at different physical scales. Interactions and interdependencies are increasing among the pathways and across the physical scales of the energy system as well as between the energy system and other systems, such as data and information networks. Energy systems integration (ESI) enables the effective analysis, design, and control of these interactions and interdependencies along technical, economic, regulatory, and social dimensions. By focusing on the optimization of energy systems across multiple pathways and scales, we can better understand and make use of potential co-benefits that increase reliability and performance, reduce cost, and minimize environmental impacts.

NREL and its partners recognize the growing importance of ESI as a critical multidisciplinary, multifaceted research and development area that will underpin the energy system of the future. We are developing a core competency to drive the development of the next generation of systems integration, simulation, operation, and controls and inform future energy system architectures, policies, and investments. We are assembling critical analytical and physical capabilities to address ESI with investments in NREL's Energy Systems Integration Facility (ESIF) and national and international work to highlight challenges and opportunities.

**Learn More:** [www.nrel.gov/esi/](http://www.nrel.gov/esi/)

### Disaster Resiliency and Recovery: Systems Thinking Helps Communities Build and Rebuild Green

NREL's energy disaster recovery program offers a broad range of services, including whole-community energy planning, on-site technical assistance, energy-efficient design and rebuilding strategies, and clear information for decision makers. Our comprehensive energy solutions address the full spectrum of disaster recovery: prevention and planning to minimize impacts; response and recovery; and rebuilding for sustainability, security, and safety.



*On May 4, 2007, a tornado destroyed or damaged 95% of the homes and businesses in Greensburg, Kansas. With help from the U.S. Energy Department and NREL, townspeople devised a plan to rebuild as a model green community for rural America. Photo by Federal Emergency Mgmt. Agency, 16290*

The disaster recovery work is a practical application of NREL's leadership in assessing the feasibility and understanding the barriers of developing "renewable energy communities," which could feature near-zero or zero-energy homes, integrated transportation modes with advanced vehicles, local renewable energy generation, and sustainable living practices.

Cost advantages from the *systems approach*—linking homes with vehicles and addressing energy issues on a community level rather than on individual households—can be gained compared to the costs of each individual part.

NREL has had the opportunity to put theory into practice in several disaster areas: New Orleans, Louisiana; Greensburg, Kansas; American Samoa; Haiti; and most recently in New York and New Jersey following Hurricane Sandy.

In the wake of Sandy, the Federal Emergency Management Agency (FEMA) funded NREL to participate in disaster recovery strategic planning efforts between federal, state, and local agencies. NREL teams provided expertise in energy aspects of sustainability and coordinated key stakeholders in the planning process to ensure the inclusion of renewable energy and energy efficiency into the planning process.

"Doing this work enables us to have a positive impact at a critical stage when federal, state, and local agencies are working together in long-term strategic planning," said NREL project leader Lynn Billman. "There is a narrow window of opportunity to influence the recovery efforts so that sustainability is prioritized in rebuilding."

### ***NREL Support for Clean Transportation Leads to Clean Parks, Clean Cities***

The U.S. Department of Energy (DOE), NREL, and the National Park Service (NPS) are collaborating to develop sustainable transportation strategies that reduce petroleum-based fuel consumption and greenhouse gases (GHGs), while enhancing the park experience. The Clean Cities National Parks Initiative deploys alternative fuels, electric-drive vehicles, and fuel-saving measures in iconic locations, including Yellowstone, Denali, and Shenandoah National Parks. These operational approaches are paired with guest outreach stressing the environmental, economic, and health benefits in the parks and the world beyond.

In its work for DOE's Clean Cities program, NREL provides NPS with strategies and support tailored to the geography, visitor patterns, and environmental considerations of each park. NPI measures include guest shuttle systems, sustainable fleet vehicles, alternative fueling stations, biodiesel produced from foodservice waste oil, and operational recommendations based on fleet data analysis.

"With these initial measures, we estimate that the parks have displaced more than 2.5 million gallons of petroleum-based fuel and prevented more than 23,000 tons of GHGs from being emitted," says NREL's Andrew Hudgins. "But this is really just the beginning. The projects are raising the profile of clean, cost-effective alternatives to petroleum by demonstrating these technologies to millions of visitors."

NREL provides technical expertise and programmatic support to nearly 100 Clean Cities coalitions across the United States. But Clean Cities and the National Parks Initiative are just two components of NREL's sustainable transportation portfolio.

### **Energy Informatics – Turning Energy Data Into Actionable Information**

Energy Informatics is the process of turning energy datasets into actionable information and decision support tools.

NREL sees high-value opportunity to become the leader in enabling action and decisions regarding energy systems integration based on complex data flows, analytic engines, and user-driven tools. This will help the laboratory fulfill a five-year initiative to build robust capabilities in closed-loop data science—a data-driven process of continuous improvement. NREL is already leading several open data initiatives that support the informatics project, including OpenEI and [api.data.gov](https://api.data.gov).





NREL conducts fundamental research that helps document comparative resource needs for various forms of energy, old and new, and helps identify potential impacts of climate change on U.S. energy systems.

Photo from iStock 16782674

We provide technical, deployment, and analytical support on the full range of sustainable transportation solutions, including biodiesel, electric, ethanol, hydrogen, natural gas, and propane vehicles. We collect, validate, and publish comprehensive data on vehicle availability, vehicle emissions, fuel economy, fueling station locations, fuel production, and policy incentives. This complements technical assistance and tools we provide to help our stakeholders evaluate and select fuels and technologies based on individual needs and goals.

### ***Fundamental Analysis: Documenting Land and Water Requirements of Energy Systems***

NREL's report on the land-use requirements of solar power plants based on actual land-use practices from existing solar facilities—***Land-Use Requirements for Solar Power Plants in the United States***—has been downloaded more than 2,300 times.

“Having real data from a majority of the solar plants in the United States will help people make proper comparisons and informed decisions,” lead author Sean Ong said. The report was written with NREL colleagues Clinton Campbell, Robert Margolis, Paul Denholm and Garvin Heath.

Ong gathered data from 72% of the solar power plants installed or under construction in the United States. Among the findings: A large fixed-tilt photovoltaic (PV) plant that generates 1 gigawatt-hour per year requires, on average, 2.8 acres for the solar panels. This means that a solar power plant that provides all of the electricity for 1,000 homes would require 32 acres of land.

“The numbers aren’t good news or bad news,” Denholm said. “The report provides fundamental data that modelers and analysts, people looking 10 or 20 years into the future, can use to evaluate the impacts solar energy may have.”

***Learn More: [www.nrel.gov/docs/fy13osti/56290.pdf](http://www.nrel.gov/docs/fy13osti/56290.pdf)***

NREL has published a substantial body on the energy-water-land nexus that helps document comparative resource needs for various forms of energy, old and new, and helps identify potential impacts of climate change on U.S. energy systems. This work includes:

- **“The Energy-Water-Food Nexus Through the Lens of Algal Systems”** by Morgan Bazilian, Doug Arent, and others; published in *Industrial Biotechnology*, August 2013
- **“Modeling Biofuel Expansion Effects on Land Use Change Dynamics”** by Ethan Warner, Daniel Inman, Benjamin Kunstman, Brian Bush, Laura Vimmerstedt, Jordan Macknick, Yimin Zhang, and others; published in *Environmental Research Letters*, January-March 2013
- **“Modeling Low-Carbon U.S. Electricity Futures to Explore Impacts on National and Regional Water Use”** by Jordan Macknick, Trieu Mai, and others; published in *Environmental Research Letters*, January-March 2013.
- **“Energy Sector Vulnerability to Climate Change: Adaptation Options to Increase Resilience,”** a presentation by Robin Newmark, Dan Bilello, Jordan Macknick, KC Hallet, Ren Anderson, and others to the Fall 2012 meeting of the American Geophysical Union.





# Emerging Economies are Reshaping the Energy and Geopolitical Landscape

Globally, demand for energy is growing as economies expand. By engaging in international efforts and working around the world to advance deployment of renewable energy and energy efficiency technologies, NREL helps countries meet this demand while supporting U.S. energy, environmental, and economic security priorities.



## 21st Century Power Partnership Enabling Power System Transformation



The **21st Century Power Partnership**, a multilateral, public-private collaboration led by the global Clean Energy Ministerial (CEM), aims to enhance the large-scale deployment of renewable energy and energy efficiency through smart policies and programs that leverage smart grid solutions and clean energy technologies.

The Power Partnership focuses on four key activities:

- Supporting country-level policy and regulatory implementation
- Developing and sharing knowledge
- Strengthening and disseminating tools
- Building capacity.

As the operating agent for the Power Partnership, NREL implements Power Partnership activities based on guidance from the CEM, the United Nations, and other partners and stakeholders.

In India and South Africa, the Power Partnership facilitates technical assistance and peer learning to support national and subnational activities by working with existing country and development assistance programs. The partnership is assisting policymakers in establishing and achieving aggressive power sector transformation roadmaps. In a separate project, NREL updated its solar resource maps for India to incorporate data developed using weather satellite measurements combined with site-time-specific solar modeling.

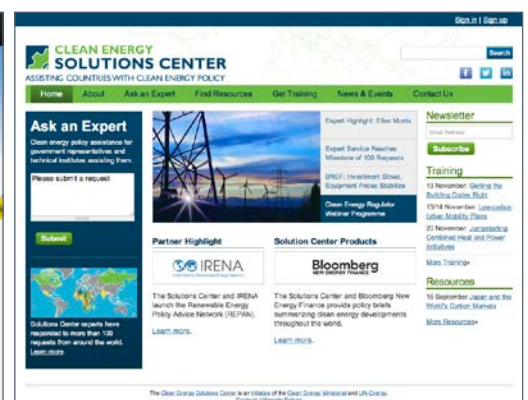
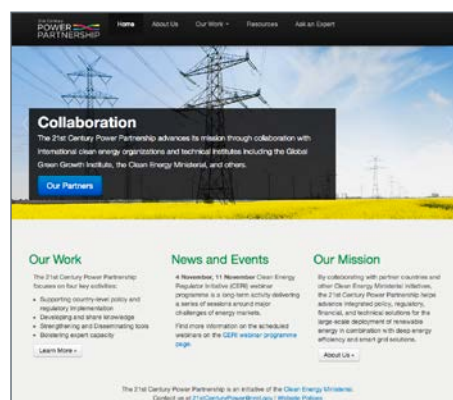
NREL is also the operating agent for the **Clean Energy Solutions Center**, another CEM initiative. The Solutions Center ([cleanenergysolutions.org](http://cleanenergysolutions.org)) helps governments, advisors, and analysts create policies and programs that advance the deployment of clean energy technologies. In 2013, the Solutions Center launched the **Global RE Opportunity Tool** (REOpp) to assist policymakers and analysts in understanding the size and location of market opportunities for cost-effective deployment of renewable technologies. The Beta version, now in release, enables analysis and visualization of the technical and economic potential for solar electric technologies ranging from residential rooftop systems to utility-scale installations.

**Learn More: [21stCenturyPower.org](http://21stCenturyPower.org)  
[CleanEnergySolutions.org](http://CleanEnergySolutions.org)**

NREL's analysts engage in clean energy initiatives around the world to support three key international strategic objectives: economic development, energy security, and environmental protection at home and abroad.

NREL collaborates with technical institutions and governments to strengthen clean energy markets by conducting resource and technology assessments, sharing policy best practices, fostering business and investment partnerships, and building capacity through training and technical support.

Learn More: [www.NREL.gov/international/](http://www.NREL.gov/international/)





### ***Expert Assistance Supports Low-Emission Development Around the World***

NREL supports two key international low emission development strategy (LEDS) initiatives focused on increasing the use of clean energy to support economic development and address global challenges such as climate change and energy security.

Through the Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) program, NREL analysts are working with Mexico's Ministry of Energy to set near-term (2014-2018) national renewable electricity capacity and generation targets. In September 2013, NREL analysts Jaquelin Cochran and MacKay Miller participated in an EC-LEDS-sponsored Grid Analysis and Policy Workshop in Mexico City, leading discussions on cost-effective options to increase system flexibility, state-of-the-art modeling and data methodologies, and effective policy approaches based on international experiences. This workshop was the kick-off for the broader effort to lay a foundation for longer-term grid integration modeling that will highlight pathways to achieving Mexico's mandate for generating 35% of its electricity from renewables by 2024.

In 2013, Sadie Cox and Caroline Uriarte led the design and delivery of the second annual workshop for the Low Emission Development Strategy Global Partnership (LEDS GP). Held in Pattaya, Thailand, the three-day workshop allowed 180 government officials, international organizations, and practitioners to exchange lessons learned and best practices on LEDS planning processes, analysis and tools, finance, and more. The meeting resulted in new funding commitments for LEDS, including Inter-American Development Bank support for LEDS work in the Latin America and Caribbean region.

### ***Reports for International Energy Agency Explore Best Practices for Using Energy Models and Next-Generation Policies to Support Renewable Energy***

In 2013, the International Energy Association-Renewable Energy Technology Deployment published two major papers featuring NREL analysis.

***RE-ASSUME: A Decision Maker's Guide to Evaluating Energy Scenarios, Modeling, and Assumptions***, by Trieu Mai, Jeffrey Logan, Nate Blair, and Patrick Sullivan of NREL and Morgan Bazilian of JISEA, attempts to better equip those who commission energy scenarios and those who directly use such scenarios to make decisions. The paper highlights assumptions and methodological issues of energy scenarios that need to be critically considered when deriving policy conclusions.

***Learn More: [iea-retd.org/archives/publications/re-assume](http://iea-retd.org/archives/publications/re-assume)***

In ***RES-E-NEXT: Next Generation of RES-E Policy Instruments***, NREL's Mackay Miller, Lori Bird, Jaquelin Cochran, and Michael Milligan, together with Morgan Bazilian of JISEA and authors from Ecar Limited and DIW Berlin, assess key considerations for the next generation of policy to support renewable sources of electricity. The paper analyzes renewable generation, grid infrastructure, and short-term and long-term security of supply.

***Learn More: [iea-retd.org/archives/publications/res-e-next](http://iea-retd.org/archives/publications/res-e-next)***

## **NREL Tools Aid Deployment of Resilient Clean Energy Solutions Around the World**

NREL models and tools help inform market-wide, regional, or longer-term decisions as well as location-specific investment or operational decisions. Through [developer.nrel.gov](https://developer.nrel.gov), we share data and algorithms and tools. APIs shared through [developer.nrel.gov](https://developer.nrel.gov) have received nearly 3 million external hits and been used by more than 600 application developers and 9,000 researchers and others.

NREL offers a broad portfolio of models and tools, often developed in conjunction with private enterprise. The *simuwatt* tool is a great example of partnership with the private sector. Produced by Concept 3D in conjunction with NREL, *simuwatt* lowers the cost and time of conducting high-quality, investment grade building energy audits.

The Navy uses NREL's Renewable Energy Optimization Tool to identify and prioritize renewable energy projects that can help meet the service's goal of 50% of sites reaching net zero by 2020. "REopt is an ideal tool for the U.S. armed services as they work to increase energy independence at global bases," said NREL GIS Specialist Dan Getman.

## ***OpenEI Positions Energy Department as Leader in Global Energy Dialogue***

A vast amount of energy-related data is generated throughout the world, but historically, access to this data has been limited. To expand access to energy data, NREL created a collaborative Web platform called OpenEI. Managed by NREL for DOE, OpenEI facilitates access to data and empowers the energy community to use and contribute to the collection. OpenEI links energy communities including policymakers, researchers, investors, and industry with valuable data, analyses, visualization tools, maps, and collaboration tools.

NREL developed OpenEI in support of the Open Government initiative and to bring the power of "crowdsourcing"—harnessing collective brainpower to tackle problems—to the energy sector.

Since its launch in 2009, OpenEI has become a recognized leader in the energy data sector. In the past year on OpenEI, 608,362 people from 193 countries visited and had 31,385 hours of content engagement. OpenEI visitors viewed 2,117,699 pages, downloaded 6,669 datasets, found an external energy app 17,774 times, and translated content into another language 2,209 times.

By providing easy access to valuable data, OpenEI facilitates analyses that can lead to a clean energy future.

## Looking Beyond Clean Energy

Focused on the nexus of energy, economy, finance, and society, the Joint Institute for Strategic Energy Analysis (JISEA) provides leading-edge, objective, high-impact research and analysis to guide global energy investment and policy decisions.

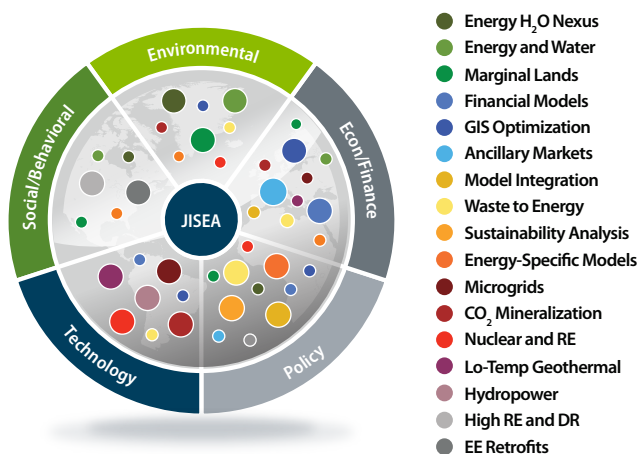
JISEA brings together the analytical expertise of NREL, Colorado School of Mines, Colorado State University, Massachusetts Institute of Technology, Stanford University, and University of Colorado-Boulder to examine questions that are beyond the scope of any single institution.

In 2012, JISEA published the first report in a body of work examining the dramatic impact of shale gas on the U.S. energy sector. *Natural Gas and the Transformation of the U.S. Energy Sector: Electricity* provided a new methodological approach to estimate natural gas GHG emissions and demonstrated the unique value of JISEA's multi-disciplinary, multi-institutional team.

Subsequently, JISEA and NREL jointly published *Opportunities for Synergy Between Natural Gas and Renewable Energy in the Electric Power and Transportation Sectors*, and a JISEA piece appeared in *The Electricity Journal*.

In 2013, JISEA-funded research and analysis was published in *IAEE Energy Forum*, and *Industrial Biotechnology*. Additional articles have been accepted for publication in *Environmental Science and Technology*, *Energy Conversion and Management*, and *IEEE Transactions of Sustainable Energy*.

**Learn More:** [www.JISEA.org](http://www.JISEA.org)



JISEA funds research projects that examine the policy, technology, social and behavioral, environmental, and economic and financial aspects of energy systems.

## NREL Analysis: 2013 Highlights

NREL published more than 300 analytical reports, journal articles, conference papers, and other materials in FY13, and these generated hundreds more news articles, blogs posts, and discussions.

**Learn More:** [www.nrel.gov/analysis/publications](http://www.nrel.gov/analysis/publications)



- ***Beyond Renewable Portfolio Standards: An Assessment of Regional Supply and Demand Conditions Affecting the Future of Renewable Energy in the West***

*David J. Hurlbut, Joyce McLaren, and Rachel Gelman*

More than 15 media outlets featured this report, including *California Science & Technology News*, *Science Daily*, *Wyoming Energy News*, and *Colorado Public Radio*. See report results on page 8.

- ***Financing U.S. Renewable Energy Projects Through Public Capital Vehicles: Qualitative and Quantitative Benefits***

*Michael Mendelsohn and David Feldman*

Increased access to public capital has the potential to reduce the cost of solar and wind energy, as measured by the levelized cost of energy, and could significantly increase the availability of project funds. Learn more on page 12.



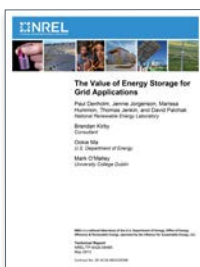
- ***Transportation Energy Futures Study (TEF)***

TEF research indicates that stopping growth in transportation sector energy use, using more biofuels, and expanding electric and hydrogen technologies have the potential to displace most transportation-related petroleum use and GHG emissions if significant barriers can be overcome. Learn more on page 8.

- ***The Value of Energy Storage for Grid Applications***

*Paul Denholm, Jennie Jorgenson, Marissa Hummon, Thomas Jenkin, and David Palchak, NREL; Brendan Kirby, Consultant; Ookie Ma, DOE; and Mark O'Malley, University College Dublin*

This report evaluates several operational benefits of electricity storage, including load leveling, spinning contingency reserves, and regulation reserves, using PLEXOS, a commercial grid simulation tool.



- ***"Assessing the Drivers of Regional Trends in Solar Photovoltaic Manufacturing"***

Published in *Energy & Environmental Science*.

*Ted James, Al Goodrich, and Michael Woodhouse, NREL; Douglas M. Powell and Tonio Buonassisi, MIT*

A majority of China's current competitive advantage in PV manufacturing comes from production scale enabled, in part, through preferred access to capital and resulting supply chain benefits, according to this study. Learn more on page 11.



- **“Energy Sector Vulnerability to Climate Change: Adaptation Options to Increase Resilience”**

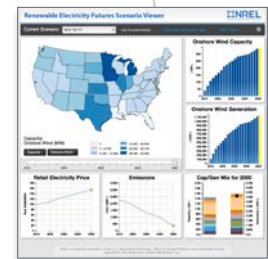
*Robin L. Newmark, Dan Bilello, Jordan Macknick, KC Hallet, Ren Anderson, NREL; Vince Tidwell, Sandia National Laboratories; Craig Zamuda, DOE*

Part of DOE’s assessment of vulnerabilities of the U.S. energy sector to climate change and extreme weather, this presentation to the American Geophysical Union Fall Meeting (Dec. 2012) seeks to quantify vulnerabilities and identify specific knowledge or technology gaps.



- **Renewable Electricity Futures Scenario Viewer**

Using data from the *Renewable Electricity Futures Study* (see page 8), this multivariate visualization tool generates more than 200,000 maps showing different scenarios, renewable technologies, and timeframes (2010–2050).



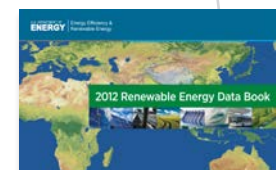
- **Geothermal Regulatory Roadmap**

This work was highlighted in a report to the President, *Rebuilding America’s Infrastructure: Cutting Timelines and Improving Outcomes for Federal Permitting and Review of Infrastructure Projects*.

- **2012 Renewable Energy Data Book**

*Rachel Gelman*

With facts and figures on energy in general, renewable electricity in the United States, and global renewable energy development and investments, the Data Book series is among the most popular items on NREL.gov.



- **“Evaluating the Impact of Third-Party Price Reporting and Other Drivers on Residential Photovoltaic Price Estimates”**

Published in *Energy Policy*.

*Carolyn Davidson and Daniel Steinberg*

This study investigates residential PV system price drivers to improve the accuracy, consistency, and relevance of PV price-tracking efforts.

## Report Card: Making an Impact

NREL analysis informs policy and investment decisions as renewable energy and energy efficiency technologies move from innovation through integration. These select examples show how NREL analysis is making an impact.

### By the Numbers

Average impact score  
of NREL journal articles

FY12: 3.57

**FY13: 4.23**

**6,308**

# of times the 2011  
Renewable Energy Data Book

was down-  
loaded from

**NREL.gov**

**20%**

Downloads of analysis  
products that are  
attributable to the

**Renewable Electricity Futures** <sup>report</sup>

**6**

# of Analysis pages  
in NREL.gov

**top 10**

most viewed pages

**25%**

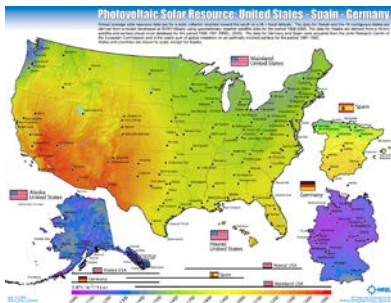
Share  
of

**NREL.gov**

FY13 page views  
attributable to analysis

### The Map

*Slate*, *Media Matters*, *The Washington Post*, *Popular Science*, and *Slashdot* all featured an NREL map by Billy Roberts in articles about the solar industry in Germany versus the United States.



### The Award Goes to...

- **Renewable Electricity Futures Study**

The Utility Variable Integration Group (UVIG) awarded Sam Baldwin (EERE), Maureen Hand, and Trieu Mai a 2013 Achievement Award “for groundbreaking contributions in the examination of electric power system operation with very high shares of wind, solar and other renewable power options.” This award reflects the work of the entire Renewable Electricity Futures team, including more than 110 people from 35 organizations.

- **Western Wind and Solar Integration Study**

UVIG also recognized Greg Brinkman and Debra Lew for “outstanding contributions to determining the impact of cycling operation due to wind and solar generation on O&M cost and emissions of coal and natural gas plants.”

- **Environmental Protection Agency’s RE-Powering America’s Land Initiative**

Harvard University’s Ash Center for Democratic Governance and Innovation recognized RE-Powering America’s Land as one of the Top 25 Innovations in American Government. In 2013, NREL is completing 26 feasibility studies under the initiative; Gail Mosey is the NREL project lead for this series of studies.

“ **At every step, NREL provides critical leadership that guides policy.**

— David Danielson

Assistant Secretary of Energy for Renewable Energy and Energy Efficiency  
U.S. Department of Energy





NREL analysis benefits from the laboratories and research facilities on NREL's 327-acre campus, including the Energy Systems Integration Facility, shown here. This Energy Department User Facility is the nation's first to help both public and private sector researchers scale up promising clean energy technologies and test how they interact with each other and the grid at utility scale. The ESIF houses more than 15 experimental laboratories and several outdoor test beds, including an interactive hardware-in-the-loop system that lets researchers and manufacturers demonstrate their products at full power and real grid load levels — up to 1 megawatt in scale. *Photo by Dennis Schroeder, NREL 28189*





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